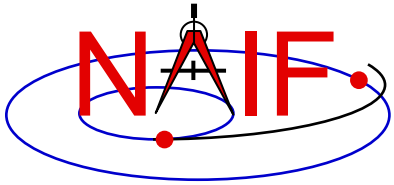


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Navigation and Ancillary Information Facility

# Introduction to Kernels

October 2022

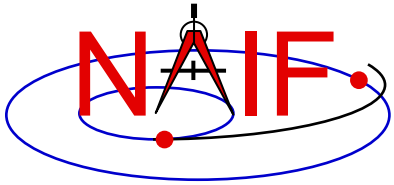


# Agenda

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Navigation and Ancillary Information Facility

- **Overview**
- **Kernel architecture**
- **Producing kernels**
- **Using kernels**



# What is a SPICE “Kernel”

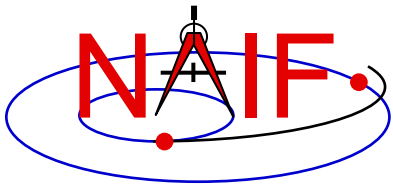
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Navigation and Ancillary Information Facility

## **“Kernel” means file**

### **“Kernel” means a file containing ancillary data**

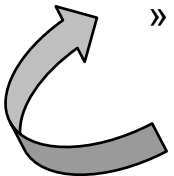
**“Kernel” means a file containing "low level" ancillary data that may be used, along with other data and SPICE Toolkit software, to determine higher level observation geometry parameters of use to scientists and engineers in planning and carrying out space missions, and analyzing data returned from missions.**



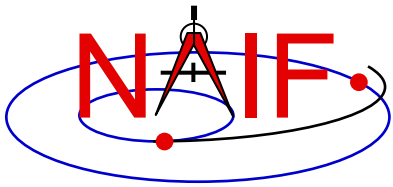
# The Family of SPICE Kernels

Navigation and Ancillary Information Facility

- **SPK**
  - Spacecraft and Planet Ephemeris
- **PCK**
  - Planetary Constants, for natural bodies
    - » Orientation
    - » Size and shape
- **IK**
  - Instrument
- **CK**
  - Orientation (“Camera-matrix”)
- **EK**
  - Events, up to three distinct components
    - » ESP: science plan
    - » ESQ: sequence
    - » ENB: experimenter’s notebook
- **FK**
  - Reference frame specifications
- **SCLK**
  - Spacecraft clock correlation data
- **LSK**
  - Leapseconds
- **MK**
  - Meta-Kernel (a.k.a. “FURNSH kernel”)
  - Mechanism for aggregating and easily loading a collection of kernel files
- **DSK**
  - Digital shape kernel
    - » Tessellated plate model
    - » Digital elevation model (under development)
- **DBK**
  - Database mechanism
    - » Primarily used to support the ESQ



EK is rarely used

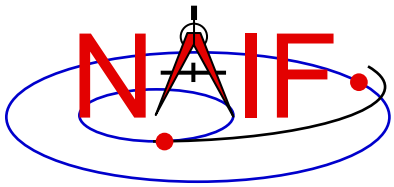


# SPICE Kernel Forms

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Navigation and Ancillary Information Facility

- **Binary form**
  - Files containing mostly data encoded in binary form
    - » They also contain a small amount of ASCII text
  - Provide rapid access to large amounts of numeric data
  - Require the use of SPICE Toolkit software to produce them
  - Require the use of SPICE Toolkit software to utilize their contents
- **Text form**
  - Files containing only printing characters (ASCII values 32-126), i.e. human-readable text.
  - Produced using a text editor
  - Require the use of SPICE Toolkit software to utilize their contents
- **“Transfer” form of a binary kernel**
  - An ASCII representation of a binary kernel
  - Was used for porting the file between computers with incompatible binary representations (e.g. PC and UNIX); no longer needed
    - » But it is one way to convert a non-native binary kernel into native format, needed for modifying the kernel or improving read efficiency



# Text and Binary Kernels

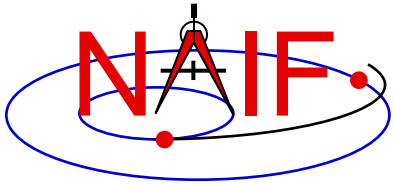
Navigation and Ancillary Information Facility

## SPICE **text** kernels are:

- text PCK (the most common type of PCK)
- IK
- FK
- LSK
- SCLK
- MK

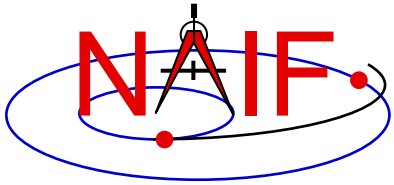
## SPICE **binary** kernels are:

- SPK
  - binary PCK (has been used only for Earth, Moon and Eros)
  - CK
  - DSK
  - ESQ (part of the E-kernel)
  - DBK (database kernel)
- } Rarely used



## Kernel Architecture

- Text kernels
- Binary kernels
- Comments in kernels



# Text Kernel Contents

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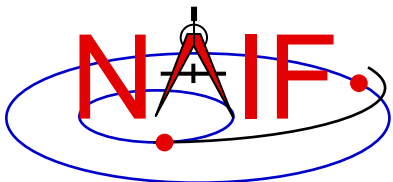
Navigation and Ancillary Information Facility

- A text kernel is a plain text file of ASCII data
- It contains assignments of the form:

```
variable_name = value(s)
```

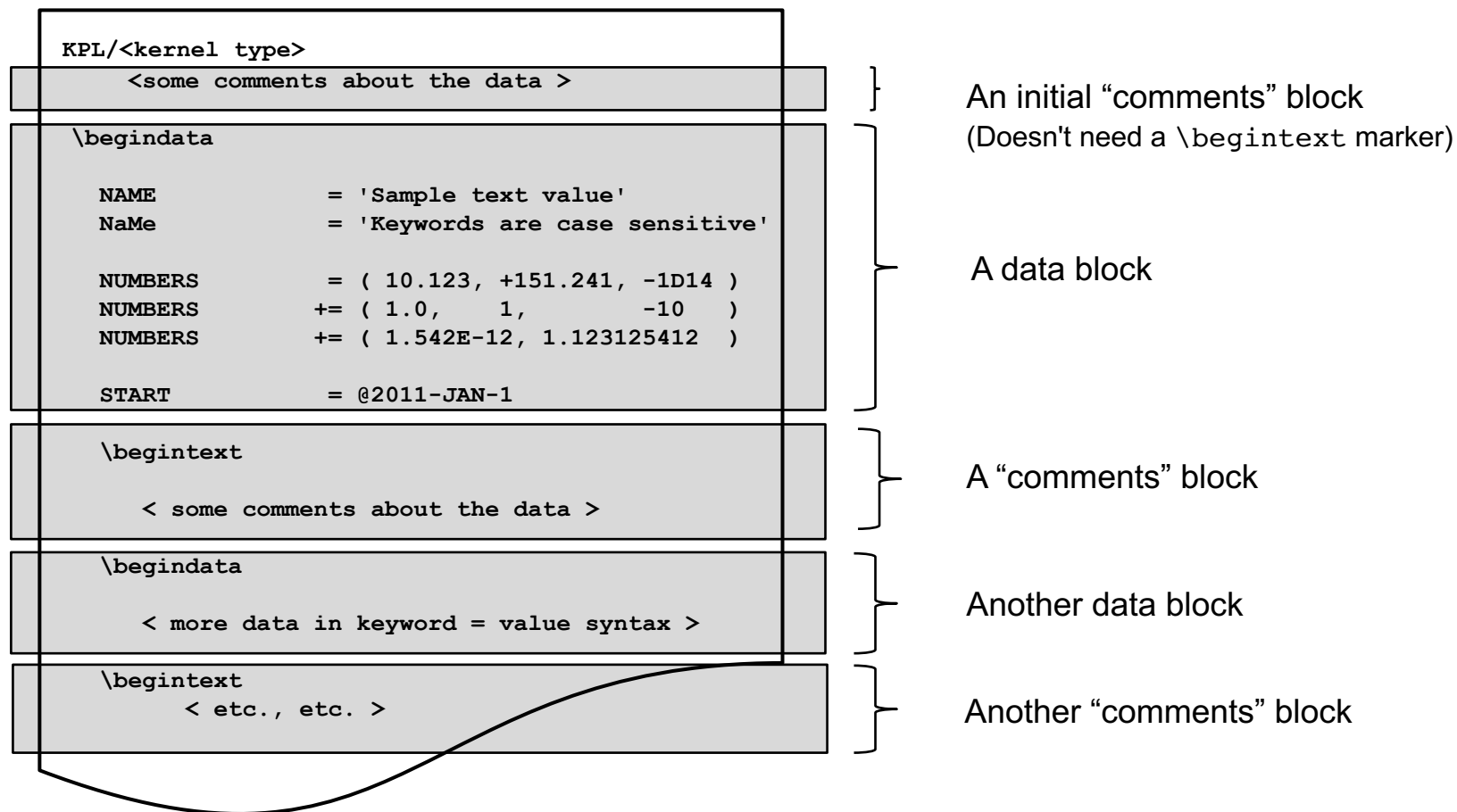
- A text kernel should also contain descriptive comments that describe the assignments
  - Comments are sometimes referred to as “meta-data”
    - » Don’t confuse this usage with the “meta-kernel” described later in this tutorial



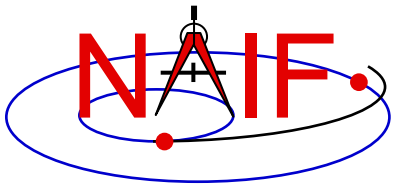


# Example Text Kernel

## Navigation and Ancillary Information Facility



- The next several pages describe what you see above
- See the “Kernel Required Reading” document for details

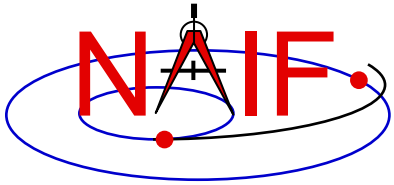


# Text Kernel Formatting

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Navigation and Ancillary Information Facility

- **KPL/<text kernel type>**
  - Its use is optional, but is highly recommended
  - Must appear on the first line, starting in column 1
  - Tells SPICE software what kind of kernel it is
  - Text kernel types are FK, IK, PCK, SCLK, MK
- **\begindata and \begintext**
  - Markers, on lines by themselves, which set off the beginning of data and the beginning of comment (metadata) blocks respectively
    - They need not begin in column 1
    - An initial set of comments need not be preceded by a \begintext marker
- **<LF> for Unix/Linux/Mac or <CR><LF> for Windows**
  - End of line marker (usually not visible when displaying a text kernel)
  - Must be present on EVERY line in the text kernel
- **Max line length, including any white space is 132 characters**

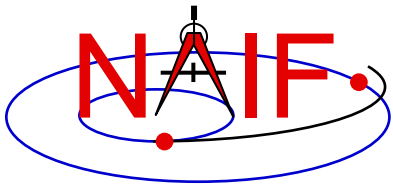


# Text Kernel Operators

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Navigation and Ancillary Information Facility

- An assignment using the “=” operator associates one or more values with a variable name.
- An assignment using the “+=” operator associates additional values with an existing variable name.
- An assignment using the “@” symbol associates a calendar date with a variable name.
  - The string will be parsed and converted to an internal double precision representation of that epoch as seconds past the J2000 epoch
    - » There is no time system implied
    - » This conversion does not need a leap seconds kernel



# Variable Names and Values

Navigation and Ancillary Information Facility

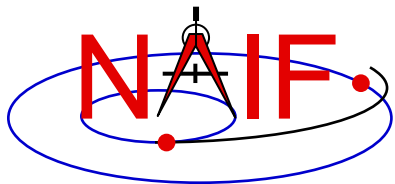
- **Variable names**

- Max of 32 characters
- Are case sensitive (**recommendation: use only upper case**)
- Cannot include space, period, parenthesis, equals sign or tab
- Recommendation: don't use the "+" sign as the last character

- **Values**

- Numeric: integer, fixed point and scientific notation are allowed
- String:
  - » enclosed in single quotes
  - » maximum length of 80 characters on a given line
    - SPICE has means to concatenate multiple string values to allow for values exceeding 80 characters
  - » string values may contain any printing ASCII character, including blank
- Time: identified by the "@" character
- Any of these three types can be provided as an n-dimensional vector of values
  - » Components are separated by commas or white space (but not TABs)
  - » Parentheses are used to enclose the vector
  - » Each string value in a vector is contained in single quotes
  - » Values in a vector must all be of the same type (numeric, string or time)

- **See "Kernel Required Reading" for more information**

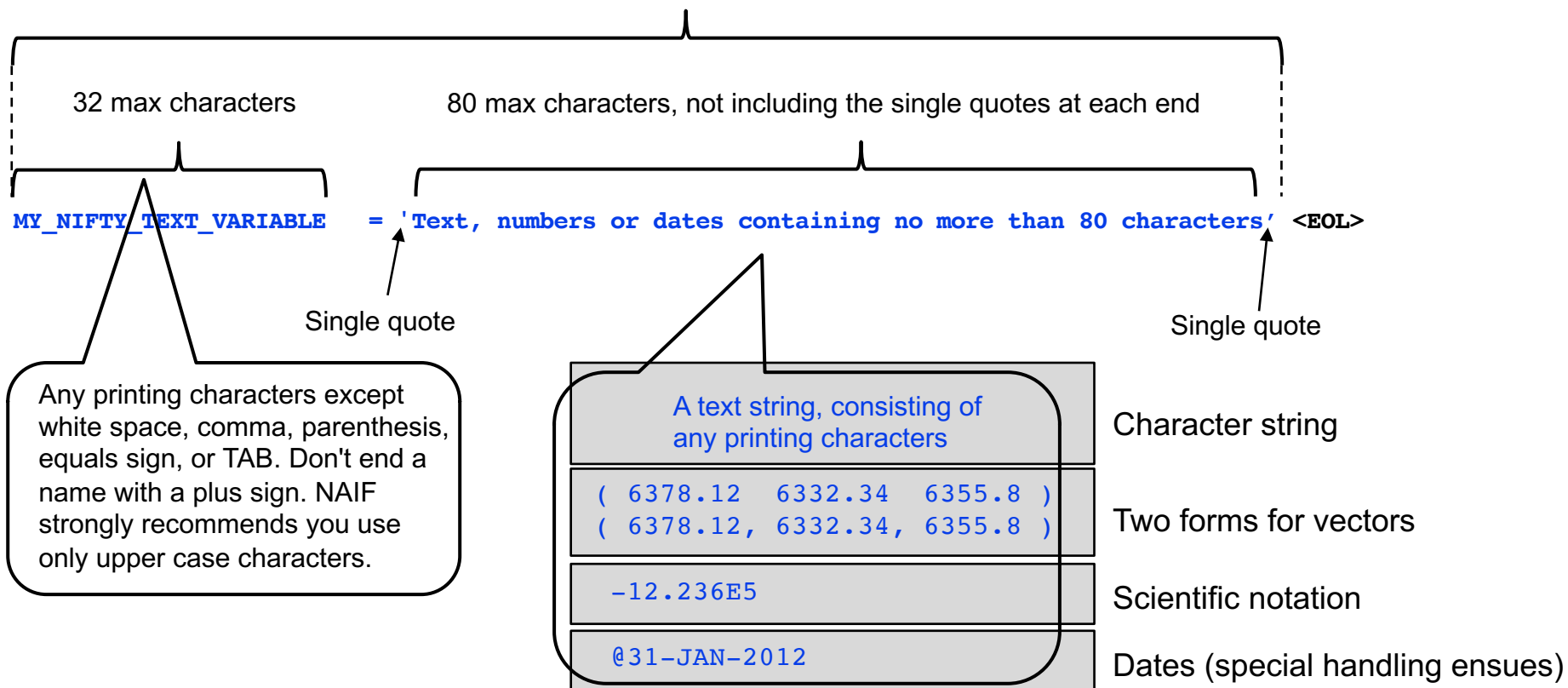


# Variable Names and Values

Navigation and Ancillary Information Facility

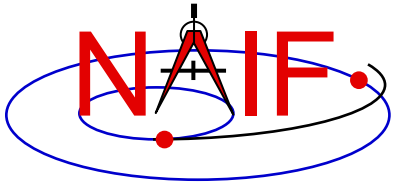
- A “picture” of the most basic text kernel assignment rules

132 max characters, with the non-printing system-dependent end-of-line indicator at the end\*



\*Unix, Linux, OSX EOL symbol: <LF>

\*DOS/Windows EOL symbol: <CR><LF>



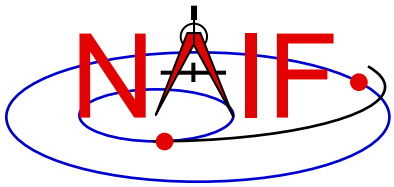
# Example Binary Kernel

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Navigation and Ancillary Information Facility

**A binary kernel contains lots of non-printing data.**

**Includes a “comment area” where descriptive meta-data provided as ASCII text should be placed.**

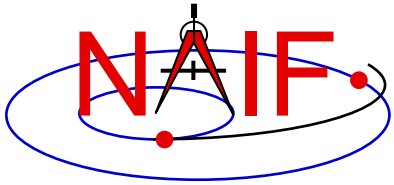


# Comments In SPICE Kernels

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Navigation and Ancillary Information Facility

- **All SPICE kernels should contain comments—descriptive information about the data contained in the file.**
  - “Comments” are also known as “meta-data”
- **See the tutorial on comments for more information.**

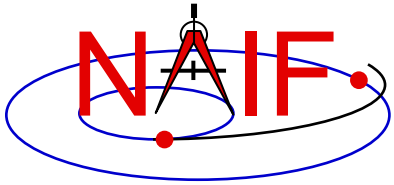


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Navigation and Ancillary Information Facility

# Producing Kernels

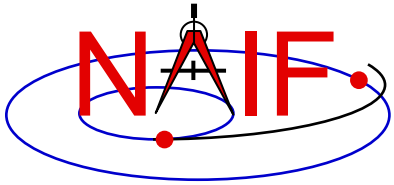




# Making a Text Kernel

Navigation and Ancillary Information Facility

- **Text kernels may be produced using a text editor**
  - Text kernels must contain only printing characters (ASCII values 32-126), i.e. human-readable text
    - » TAB characters are allowed but **HIGHLY DISCOURAGED**
    - » Caution: some text editors insert non-printing characters
  - Text kernels must have each line terminated with the end-of-line indicator appropriate for the operating system you are using
    - » For Unix, PC/Linux, Mac OSX: **<LF>**
    - » For PC/Windows: **<CR><LF>**
    - » **Don't forget to insert the end-of-line indicator on the very last line of the kernel!**
  - Fortran toolkit software will detect and warn you if trying to read a non-native text kernel. (Not needed for other languages.)
    - » Caution: this warning doesn't work for a file smaller than 132 bytes
  - See the **BACKUP** for information on converting text kernels between these two line termination techniques

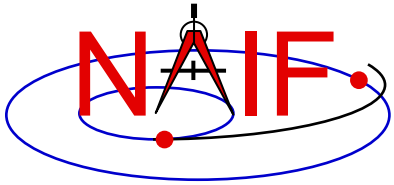


# Making a Binary Kernel

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Navigation and Ancillary Information Facility

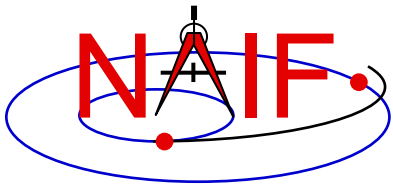
- **Binary kernels are made using Toolkit utility programs, or by using Toolkit APIs built into your own application program**
- **See “How Kernels are Made and Used” in the BACKUP section for a bit more information**
- **See the “Making an SPK” and “Making a CK” tutorials**



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Navigation and Ancillary Information Facility

# Using Kernels

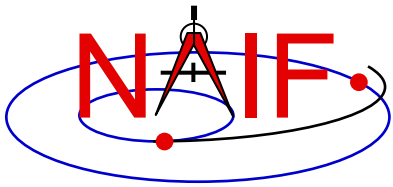


# Loading Kernels - 1

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Navigation and Ancillary Information Facility

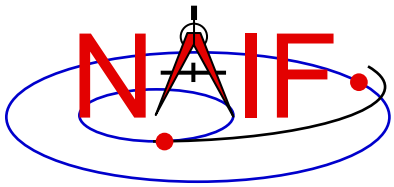
- To make kernels available to a program you “load” them
- When you load a text kernel:
  - the file is opened
  - the kernel contents are read into memory
    - » variable names and associated values are stored in a data structure called the “kernel pool”
  - the file is closed
- When you load a binary kernel:
  - the file is opened
  - for SPK, CK, binary PCK and DSK files, no data are read until a read request is made by Toolkit software
  - for ESQ files, the schema description is read, checked, and stored in memory at load time, but no data are read until a query/fetch is made
  - for all practical purposes the binary file remains open unless specifically unloaded by you



# Loading Kernels - 2

Navigation and Ancillary Information Facility

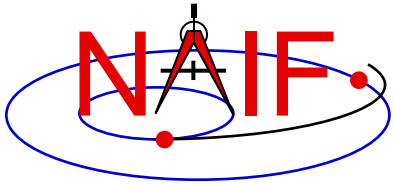
- Use the FURNISH routine to load all kernels – text and binary
  - `CALL FURNISH ( 'name.ext' )` (Fortran)
  - `furnsh_c ( "name.ext" );` (C)
  - `cspice_furnsh, 'name.ext'` (IDL)
  - `cspice_furnsh ( 'name.ext' )` (MATLAB)
  - `spiceypy.furnsh ( 'name.ext' )` (Python using SpiceyPy)
- Best practice: don't hard code filenames as shown above—instead, list them in a “meta-kernel” and load the meta-kernel using FURNISH
  - `CALL FURNISH ( 'meta-kernel_name' )` (Fortran example)
  - Look further down for more information on meta-kernels
- Caution: “Transfer format” versions of binary kernels can not be loaded; they must first be converted to binary with the Toolkit utility program *tobin* or *spacit*



# Run-time Translation

Navigation and Ancillary Information Facility

- **Binary kernels, whether or not in native binary format, may be read by any of the toolkits**
  - Accomplished by run-time translation built into Toolkit code
  - Run-time translation does NOT apply to writing to an existing binary kernel
- **Text kernels may be read by any of the C, IDL and Matlab Toolkits no matter if the end-of-line terminator is Windows style (<CR><LF>) or OSX/Linux style (<LF>)**
  - Accomplished by run-time translation built into Toolkit code
  - **Run-time translation does NOT work for Fortran Toolkits: these Toolkits read text kernels only in native format**

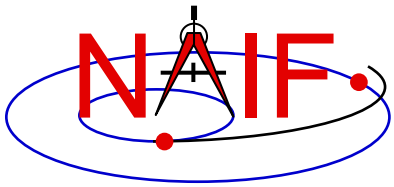


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Navigation and Ancillary Information Facility

## Meta-Kernels

**These help make kernel management easy!**



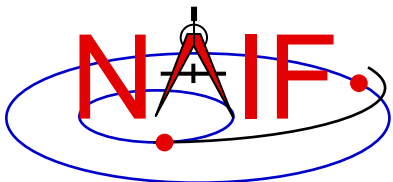
# What is a “Meta-Kernel”

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Navigation and Ancillary Information Facility

- **A meta-kernel is a file that lists names (and locations) of a collection of SPICE kernels that are to be used together in a SPICE-based application**
  - Loading the meta-kernel causes all of the kernels listed in it to be loaded
- **Using a meta-kernel makes it easy to manage which SPICE files are loaded into your program. You don’t need to revise your code—just edit your meta-kernel**
- **A meta-kernel is implemented using the SPICE text kernel standards**
  - Refer to the Kernel Required Reading technical reference for details
- **The terms “meta-kernel” and “FURNISH kernel” are used synonymously**





# Sample Meta-Kernel

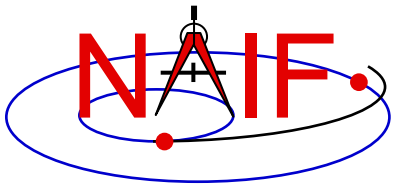
Navigation and Ancillary Information Facility

KPL/MK

\begindata

```
KERNELS_TO_LOAD = (  
    '/home/mydir/kernels/lowest_priority.bsp',  
    '/home/mydir/kernels/next_priority.bsp',  
    '/home/mydir/kernels/highest_priority.bsp',  
    '/home/mydir/kernels/leapseconds.tls',  
    '/home/mydir/kernels/sclk.tsc',  
    '/home/mydir/kernels/c-kernel.bc',  
    '/home/mydir/kernels+',  
    '/custom/kernel_data/p_constants.tpc',  
)
```

All the commas  
are optional



# Sample Meta-Kernel

Navigation and Ancillary Information Facility

KPL/MK

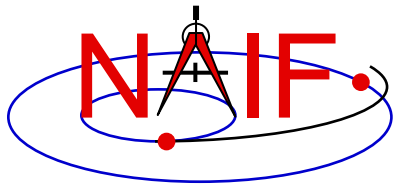
```
\begindata
```

```
  KERNELS_TO_LOAD = (  
    '/home/mydir/kernels/lowest_priority.bsp',  
    '/home/mydir/kernels/next_priority.bsp',  
    '/home/mydir/kernels/highest_priority.bsp',  
    '/home/mydir/kernels/leapseconds.tls',  
    '/home/mydir/kernels/sclk.tsc',  
    '/home/mydir/kernels/c-kernel.bc',  
    '/home/mydir/kernels+',  
    '/custom/kernel_data/p_constants.tpc',  
  )
```

All the commas  
are optional

- The last file listed in this example (p\_constants.tpc) demonstrates how to use the continuation character, '+', to work around the 80 character limitation imposed on string lengths by the text kernel standards.

- See the next two pages for some important OS-specific details!



# Unix/Mac Sample Meta-Kernel

Navigation and Ancillary Information Facility

- This meta-kernel uses the `PATH_VALUES` and `PATH_SYMBOLS` keywords to specify the directory where the kernels are located.

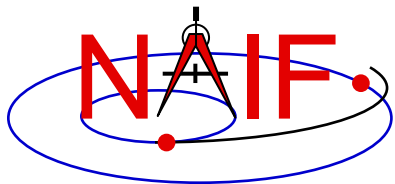
KPL/MK

```
\begindata
```

```
  PATH_VALUES      = ( '/home/mydir/kernels' )
  PATH_SYMBOLS     = ( 'KERNELS' )
  KERNELS_TO_LOAD = (
    '$KERNELS/lowest_priority.bsp',
    '$KERNELS/next_priority.bsp',
    '$KERNELS/highest_priority.bsp',
    '$KERNELS/leapseconds.tls',
    '$KERNELS/sclk.tsc',
    '$KERNELS/c-kernel.bc',
    '$KERNELS/custom/kernel_data/p_constants.tpc'
  )
```

UNIX/MAC style path notation, using forward slashes

- Although the OS environment variable notation `$<name>` is used to refer to the symbols specified using the `PATH_VALUES` and `PATH_SYMBOLS` keywords, **these symbols are NOT operating system environment variables and are set and used for substitution by SPICE only in the context of this particular meta-kernel.**
- The '+' continuation character described on the previous page may be used to handle path strings that exceed 80 characters.



# Windows Sample Meta-Kernel

Navigation and Ancillary Information Facility

- This meta-kernel uses the PATH\_VALUES and PATH\_SYMBOLS keywords to specify the directory where the kernels are located.

KPL/MK

```
\begindata
```

```
  PATH_VALUES      = ( 'c:\home\mydir\kernels' )
```

```
  PATH_SYMBOLS     = ( 'KERNELS' )
```

```
  KERNELS_TO_LOAD = (
```

```
    '$KERNELS\lowest_priority.bsp',
```

```
    '$KERNELS\next_priority.bsp',
```

```
    '$KERNELS\highest_priority.bsp',
```

```
    '$KERNELS\leapseconds.tls',
```

```
    '$KERNELS\sclk.tsc',
```

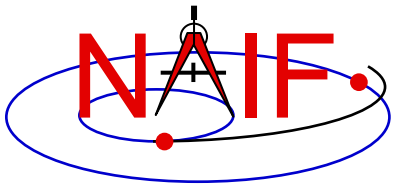
```
    '$KERNELS\c-kernel.bc',
```

```
    '$KERNELS\custom\kernel_data\p_constants.tpc'
```

```
)
```

Windows style path  
notation, using  
backwards slashes

- Although the OS environment variable notation \$<name> is used to refer to the symbols specified using the PATH\_VALUES and PATH\_SYMBOLS keywords, **these symbols are NOT operating system environment variables and are set and used for substitution by SPICE only in the context of this particular meta-kernel.**
- The '+' continuation character described on the previous page may be used to handle path strings that exceed 80 characters.

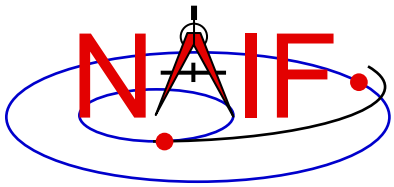


# Limits on Loaded Kernels (N67)

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Navigation and Ancillary Information Facility

- **The number of all types of kernels that may be loaded at any time is large, but limited.**
  - As of the version N67 Toolkits it is limited to 5,300
    - » Assumes each kernel has been loaded only once, and not unloaded.
- **As of the version N67 Toolkits the number of binary kernels that may be loaded at the same time is limited to 5000**
  - Binary kernel types are: SPK, binary PCK, CK and DSK
    - » Also the rarely used ESQ
- **There are also limits on the number of keywords and values for all loaded text kernels:**
  - Maximum number of keywords is 26,003
  - Maximum number of numeric data items is 400,000
  - Maximum number of character data items is 15,000

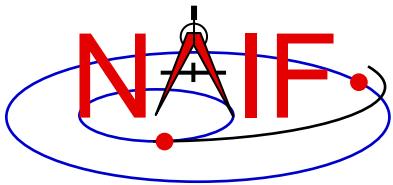


# Kernel Precedence Rule

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Navigation and Ancillary Information Facility

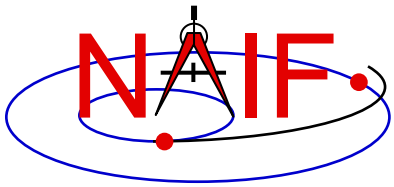
- **The order in which SPICE kernels are loaded at run-time determines their priority when requests for data are made**
  - For binary kernels, data from a higher priority file will be used in the case when two or more files contain data overlapping in time for a given object.
    - » For SPKs, CKs, and binary PCKs the file loaded **last** takes precedence (has higher priority).
    - » For DSKs, use of priority will be specified via API calls
      - » Not yet supported as of N67 Toolkits
    - » Priority doesn't apply to ESQ files – all data from all loaded files are available.
  - If two (or more) text kernels assign value(s) to a single keyword using the “=” operator, the data value(s) associated with the last loaded occurrence of the keyword are used—all earlier values are replaced with the last loaded value(s).
  - Orientation data from a binary PCK always supersedes orientation data (for the same object) obtained from a text PCK, no matter the order in which the kernels are loaded.



# Unloading Kernels

Navigation and Ancillary Information Facility

- The unloading of a kernel is infrequently needed for FORTRAN or CSPICE applications but is **essential** for Icy, Mice, Python and similar interpreter scripts.
  - Because of the way IDL and MATLAB interact with external shared object libraries, any kernels loaded during an IDL or MATLAB session will stay loaded until the end of the session unless they are specifically unloaded.
- The routines KCLEAR and UNLOAD may be used to unload kernels containing data you wish to be no longer available to your program.
  - KCLEAR unloads all kernels and clears the kernel pool
  - UNLOAD unloads specified kernels
  - KCLEAR and UNLOAD are only capable of unloading kernels that have been loaded with the routine FURNISH. They will not unload any files that have been loaded with older load routines such as SPKLEF (those used prior to availability of FURNISH).
- Caution: unloading text kernels with UNLOAD will also remove any kernel pool data provided through the kernel pool run-time data insertion/update APIs (PCPOOL, PDPOOL, PIPOOL).



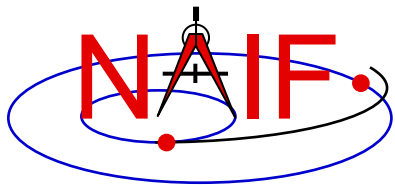
# Backup

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Navigation and Ancillary Information Facility

- **How kernels are made and used**
- **Why and how kernels are modified**
- **SPICE data structures hierarchy**
- **Problems making text kernels**



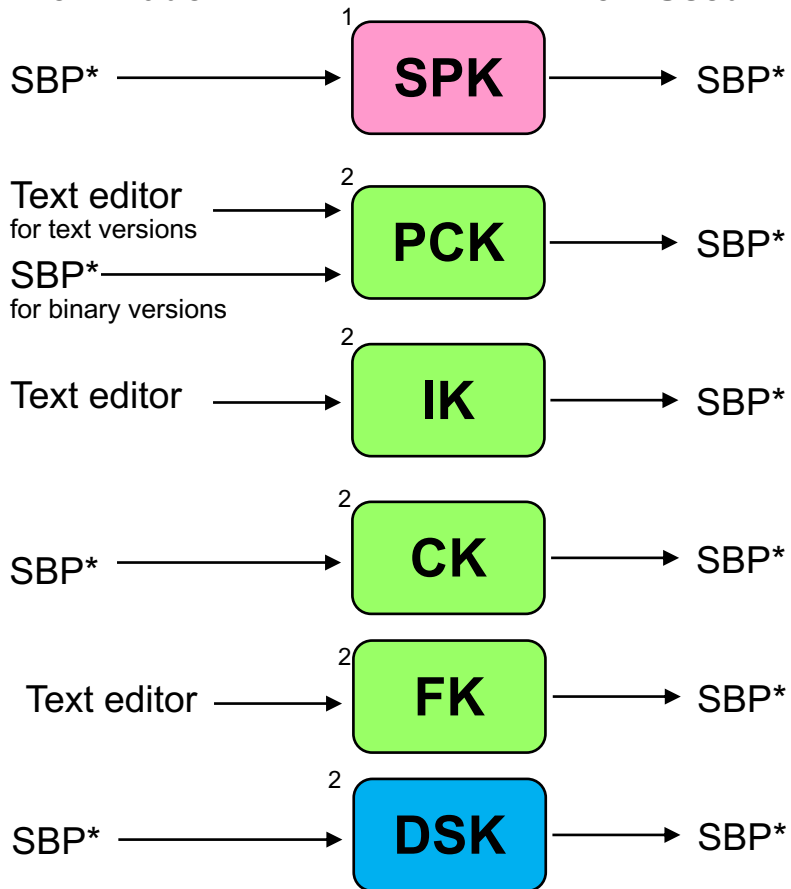


# How Kernels are Made and Used at JPL

## Navigation and Ancillary Information Facility

### How Made?

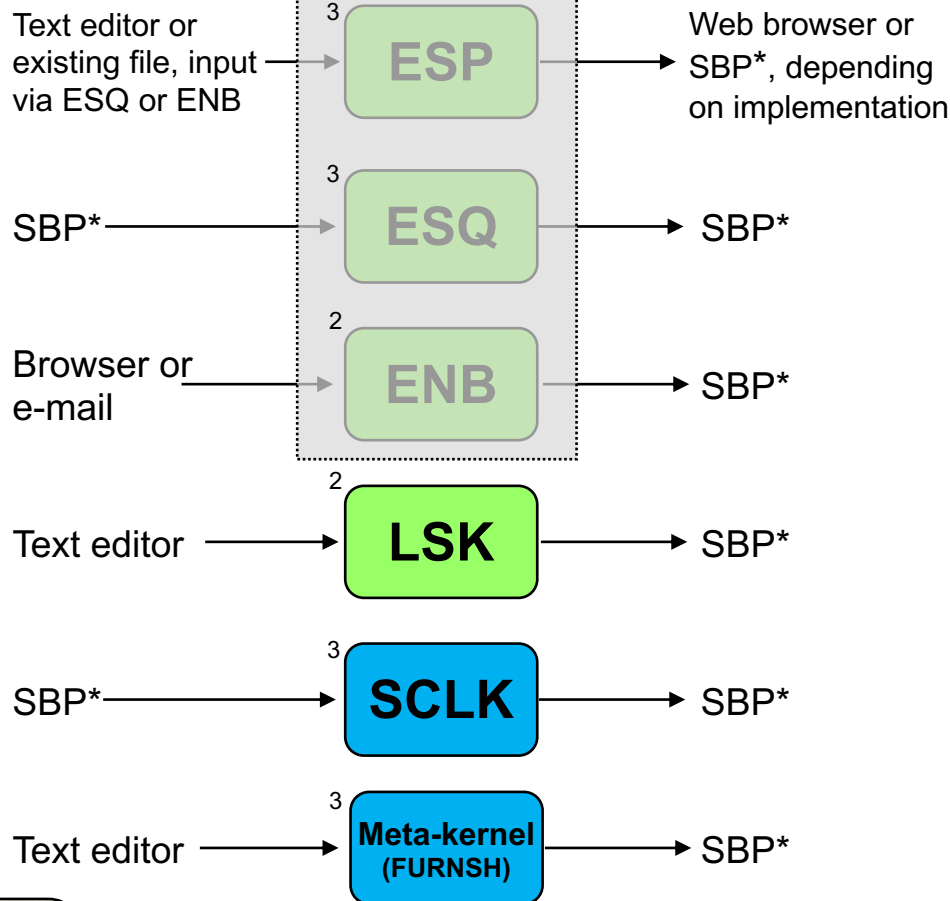
### How Used?



### How Made?

### The EK family

### How Used?

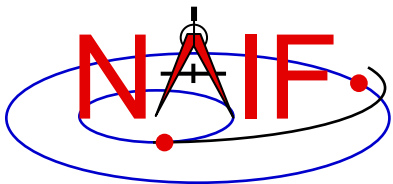


### Who usually makes the kernels at JPL?

- 1   NAV and NAIF
- 2   NAIF
- 3   NAIF or other

This represents current practice for most JPL missions, but is by no means a requirement. **Anyone can make SPICE files.**

**\*SBP** = SPICE-based program that uses modules from the SPICE Toolkit. In some cases the Toolkit contains such a program already built. In some cases NAIF may have such a ready-built program that is not in the SPICE Toolkit.



# Why & How Kernels are “Modified” - 1

## Navigation and Ancillary Information Facility

### File Type

### Why Modified

### How Modified

**SPK**

- To add comments
- To merge files or subset a file
- To correct/revise an object ID

- COMMNT, SPACIT or SPICELIB module
- SPKMERGE, DAFCAT
- BSPIDMOD

**PCK**

Text version

- To revise data values
- To add additional data items and values

- Text editor
- Text editor

**IK**

- To revise data values
- To add additional data items and values

- Text editor
- Text editor

**CK**

- To add comments
- To merge files
- To revise the interpolation interval
- To subset a file

- COMMNT, SPACIT, or SPICELIB module
- DAFCAT, CKSMRG
- CKSPANIT, CKSMRG
- CKSLICER

**FK**

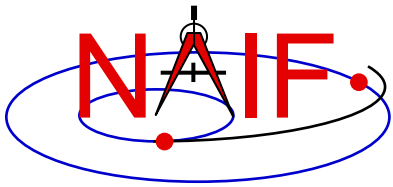
- To revise data values
- To add additional data items and values

- Text editor
- Text editor

**DSK**

- To add comments
- To merge files
- To modify segment attributes

- COMMNT, SPACIT or SPICELIB module
- DLACAT
- DSKMOD



# Why & How Kernels are “Modified” - 2

## Navigation and Ancillary Information Facility

### File Type

### Why Modified

### How Modified

The **EK** family

**ESP**

- To add, revise or delete “data”
- To add comments

- (Depends on implementation)
- (Depends on implementation)

**ESQ**

- To add additional data
- To revise data
- To delete data
- To add comments
- To merge files

- Toolkit modules
- Toolkit modules
- Toolkit modules
- COMMNT, SPACIT or SPICELIB module
- (under development)

**ENB**

- To change entry status (public <--> private)
- To delete an entry

- WWW
- WWW

**LSK**

- To add a new leapsecond

- Text editor

**SCLK**

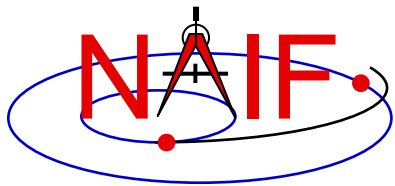
- To add comments

- Text editor

**Meta-kernel  
(FURNISH)**

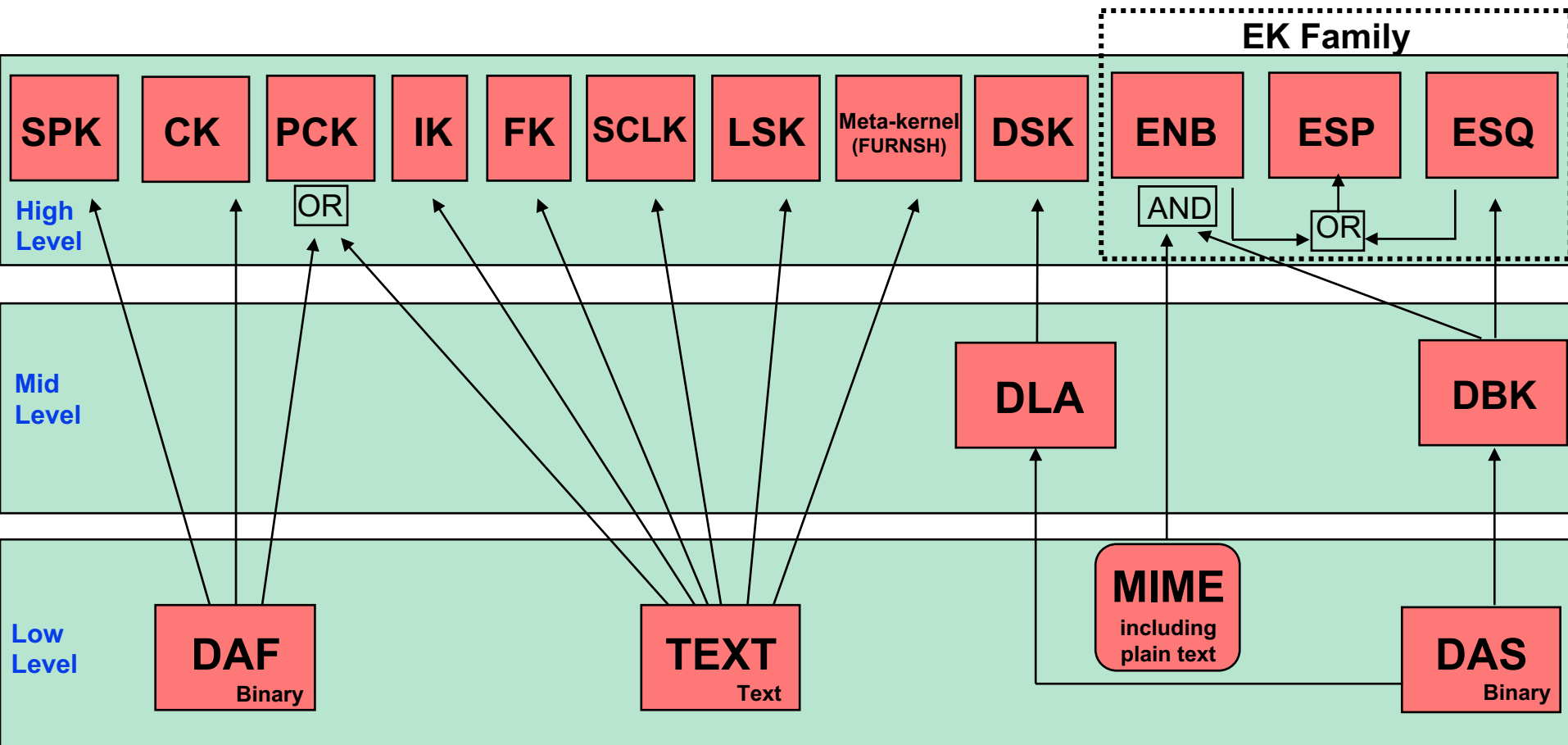
- To add or remove kernels to be used in a program

- Text editor



# SPICE Data Structures Hierarchy

Navigation and Ancillary Information Facility



DAF = Double Precision Array File

DBK = Data Base Kernel

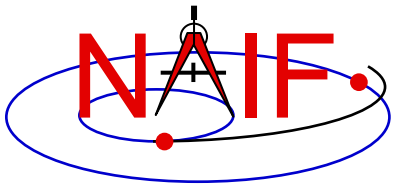
DAS = Direct Access, Segregated

DSK = Digital Shape Kernel (under development)

DLA = DAS Linked Array (under development)

Excepting MIME, each of these data structures is built entirely of SPICE components.

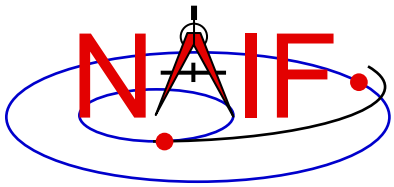
PCK files are usually text-based, but binary versions exist for the earth and moon. The ESP has been implemented using both the ENB and ESQ mechanisms. The DBK is a SQL-like, homebrew database.



# Problems Making Text Kernels

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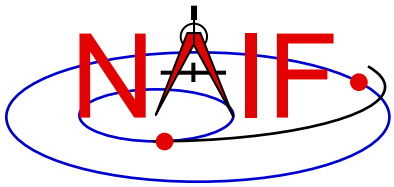
- **Cutting/pasting complete, or pieces of, data assignments or `\begindata` or `\begintext` markers into a text kernel can cause a problem**
  - It may result in insertion of non-printing characters or incorrect end-of-line terminators
  - This is not a problem for comments, but it is probably best to treat all portions of a text kernel the same
- **If creating a text kernel by editing an existing one:**
  - first save a backup copy
  - be sure you are starting with a file in native format for the computer you are using: either Unix/Linux/Mac or Windows
  - use single quotes around any string (character) values
  - be sure to insert a final end-of-line marker at the end of your last line of data or text
    - » Press the “return” key to accomplish this



# Some Useful Tools - 1

Navigation and Ancillary Information Facility

- **For a Unix or Linux (including Mac) environment**
  - In order to display all non-printing characters, display tab characters as “^I”, and place a “\$” character at the end of each line:
    - » `cat -et <file name>`
  - How do end-of-line markers appear when displayed in a text file using the `cat -et` command?
    - » Unix/Linux/Mac: \$ (line feed)
    - » Windows: ^M\$ (carriage return followed by line feed)
  - In order to display the file type, language used, and end of line marker
    - » `file <file name>`
    - » **Examples using Unix and Windows (“PC”) versions of the SPICE leapseconds kernel:**
      - `file naif0010.tls`  
`naif0010.tls: ASCII English text`
      - `file naif0010.tls.pc`  
`naif0010.tls.pc: ASCII English text, with CRLF line terminators`



# Some Useful Tools - 2

Navigation and Ancillary Information Facility

- **For a Unix or Linux (including Mac) environment**
  - To convert a Unix/Linux/Mac text kernel to Windows (“DOS”) style:
    - » `unix2dos <filename>`
  - To convert a Windows (“DOS”) style text kernel to Unix/Linux/Mac style:
    - » `dos2unix <filename>`
  - Unix2dos and dos2unix are often available on Unix-based computers, and may be easily obtained from the [www](http://naif.jpl.nasa.gov/naif/utilities.html)
  - Alternatively, to convert either style text kernel to the other style, use the SPICE “bingo” program
    - » The bingo program and User Guide are available only from the NAIF/Toolkit/Utilities web page:
      - <http://naif.jpl.nasa.gov/naif/utilities.html>
- **More information**

In Wikipedia, search on “newline” or “unix2dos”